Fresh Fruit & Vegetable
Pre-cooling

for Market Gardeners in Alberta

Alberta
AGRICULTURE, FOOD AND
RURAL DEVELOPMENT
AGDEX 736-14

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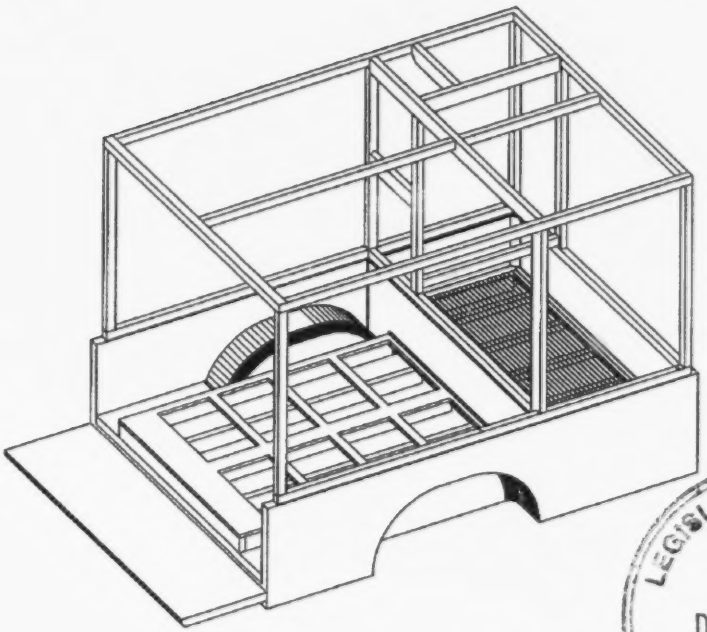

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John Kienholz and Ike Edeogu

Alberta
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This publication contains a discussion of issues related to development of pre-cooling and handling of fresh produce. The purpose of the publication is to provide information that will help guide the development of pre-cooling and handling systems for small market gardeners. It is not intended for any other purpose. While every effort has been made to ensure that the information in this publication is correct at the time of printing, neither the Crown, its agents or employees, nor the authors of this publication assume any responsibility or liability whatsoever for any financial loss or damage suffered as a result of the publication or use of these materials or as a result of any changes in the law after publication of these materials.

It is recommended that the professional services of an engineer be sought in designing facilities for post-harvest cooling, storage and handling of fresh produce.

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Introduction

Pre-cooling is the key component in the preservation of quality for perishable fresh produce in post-harvest systems. Pre-cooling is also very closely linked to the other operations such as handling and storage.

The practice of pre-cooling fruits and vegetables after harvest has existed for many years. In that time, several methods and techniques of pre-cooling were developed, primarily to meet requirements of the large producers and markets in the United States and Europe.

Pre-cooling

Interest in pre-cooling fresh fruits and vegetables is increasing in Alberta. These products need an improved shelf life and must be of high quality to enter and compete in retail markets. Many Alberta market gardeners, however, do not pre-cool their produce. Often, they do not pre-cool because of the initial costs involved, the problem in deciding which pre-cooling method to use and not knowing how to effectively set up a pre-cooling process.

This publication discusses the various cooling technologies and the basis for selecting and setting up systems that will meet the needs of a wide range of market gardeners.

What is Pre-cooling?

Pre-cooling is the rapid removal of heat from freshly harvested produce. This process is typically done before the produce is shipped to market or put into cold storage.

Although produce may be pre-cooled in a cold storage facility, pre-cooling differs from cold storage. In cold storage, the temperature is simply maintained at a predetermined low temperature. If the cold storage facility is to double as a pre-cooling facility, higher refrigeration capacity is required as well as appropriate provisions for pre-cooling and handling of the produce.

Why Pre-cool Fresh Produce?

Fresh produce starts to deteriorate immediately following harvest. Respiration due to enzymatic oxidation in the growing produce continues after harvest. This process results in the consumption of sugars, starches and moisture without replenishment by the plant.

Carbon dioxide and other gases along with heat are generated in the process. If the heat is not removed, the process is accelerated. Growth of molds and the loss of moisture from the produce are also accelerated by heat.

Bruising of the produce further accelerates these processes, resulting in the loss of texture, firmness, colour, flavour and appearance. In addition, some nutritional value may also be lost. When these losses occur, the produce is generally considered to have lost its freshness and quality.

Rapid lowering of produce temperature and then maintaining it at a constant low temperature minimizes the enzymatic and other processes that cause these losses. Pre-cooling as quickly as practical is therefore a very important requirement for maintaining optimum produce quality, especially for those types with naturally high respiration rates. Other benefits resulting from pre-cooling fruits and vegetables include the following:

- **minimized production losses**

Weather variability during the harvest season can cause produce to mature earlier or later than planned. If the produce is not harvested at the optimum time, losses will occur. Late harvesting may also occur if market opportunities are not available at the desired time. Pre-cooling and cold storage are valuable tools that better allow produce to be harvested on time and sold when markets become available.

- **improved economics of harvest operations**

The daily harvest may be increased with the assurance that produce quality will be preserved. This confidence permits harvesting to be done over a longer period, thus spreading out workloads. Daily harvest hours could also be extended because the effect of ambient temperatures on the produce would be lessened. This flexibility results in better use of equipment and personnel.

- **minimized losses during marketing**

Some types of produce spoil very quickly if not pre-cooled immediately after harvest. These types have to be sold within a day or two of harvesting to be of acceptable quality. Strawberries are a good example. Other examples are leafy vegetables that require trimming to maintain a fresh appearance. Pre-cooling extends the shelf life and thus the opportunity for sale before the produce is no longer marketable. See Table 1.

- **improved utilization by consumer**

Consumers can be supplied with top quality produce with a longer shelf life through pre-cooling. This extended shelf life lessens the urgency to consume or process produce quickly after it is purchased. Consumers are more likely to make larger purchases, enjoy lower handling costs and have more timely product utilization.

- **expanded market opportunities**

Retail marketers require produce of the highest quality that has longest practical shelf life. A highly perishable product that is not pre-cooled, kept cold and handled with care will lose quality and have difficulty competing with a quality imported product. It is also difficult for the lower quality product to meet grading standards. Pre-cooling is, therefore, the key for perishable produce to enter and compete in retail markets.

Factors Contributing to Spoilage

Different types of fruits and vegetables spoil naturally at different rates. Table I shows the length of time fresh produce (not rapidly pre-cooled) will last in a refrigerator at 4 degrees centigrade.

Rapid pre-cooling and storage at a stable temperature will extend this shelf life for most produce subject to rapid spoilage. For higher storage temperatures, it is a generally accepted rule of thumb that "deterioration of fresh produce doubles for every 10 degrees centigrade above the optimum storage temperature." Types of produce with high spoilage rates are often of higher value than those with low spoilage rates. This aspect makes control of spoilage an especially important factor for them.

Produce such as onions, potatoes and winter squash spoil rapidly if not cured as soon as possible after harvest. Curing at an elevated temperature heals cuts and bruises and forms a tight outer skin that resists further deterioration.

Atmospheres in storages also affect the spoilage rate. Excess carbon dioxide and insufficient oxygen result in rapid deterioration and off flavours. Ethylene produced by some fruits accelerates the ripening of many fruits. It is therefore important to consider the gases that will be associated with the cold storage.

Table 1. Shelf-life of Fruits and Vegetables Refrigerated at 4°C for Best Flavour and Nutrition

#	Product	Shelf-life	#	Product	Shelf-life
1	Asparagus	2 days	19	Peas	less than 1 day
2	Beans (green,wax)	5 days	20	Peppers	7 days
3	Beets	21 - 28 days	21	Potatoes (mature)	9 months (7 - 10°C)
4	Broccoli	3 days	22	Potatoes (new)	7 days
5	Brussel sprouts	5 days	23	Pumpkins	-no data -
6	Cabbage	14 days	24	Radishes	- no data -
7	Carrots (mature)	several weeks	25	Raspberries	2 days
8	Carrots (young)	14 days	26	Rhubarb	3 days
9	Cauliflower	10 days	27	Rutabagas	several weeks
10	Celery	14 days	28	Saskatoons	- no data -
11	Chinese Vegetables	- no data -	29	Spinach	4 days
12	Cucumbers	10 days	30	Squash (summer)	7 days
13	Kohlrabi	- no data -	31	Squash (winter)	several months
14	Leafy Greens	- no data -	32	Strawberries	2 days
15	Leeks	- no data -	33	Sweet Corn	less than 1 day
16	Lettuce	7 days	34	Swiss Chard	- no data -
17	Onions	28 days	35	Tomatoes	7 days
18	Parsnips	28 days	36	Zucchini	- no data -

(Adapted from Publication 1695, Agriculture Canada).

Significant moisture loss affects the appearance and firmness of produce. Table 2 shows the maximum amount of moisture the produce may lose before losing its appearance and firmness. Room cooling, forced air cooling and vacuum cooling all remove some moisture from produce during pre-cooling. The amount of moisture lost will depend on design and operation of the system. More moisture will be lost if the produce is held for extended periods before cooling.

Water used in direct contact with the produce can affect produce quality as well. Rapid deterioration and off flavours can be triggered by water containing iron, high levels of minerals, bacteria and other organic material.

Contaminated water used on fresh produce can also mean that people who consume it become ill. The cleanliness, quality and sanitation of water used in produce facilities is therefore very important.

Table 2. Percentage of Weight (Moisture) Loss from Fruits and Vegetable that Affects Produce Quality after Harvest

#	Product	Weight Loss (%)	#	Product	Weight Loss (%)
1	Asparagus	8.0	19	Peas	5
2	Beans (broad, runner, snap)	6.0, 5.0, 41.0	20	Peppers	7.0
3	Beets	7.0	21	Potatoes (mature)	7.0
4	Broccoli	4.0	22	Potatoes (new)	7.0
5	Brussel sprouts	8.0	23	Pumpkins	- no data -
6	Cabbage	8.0	24	Radishes	- no data -
7	Carrots (mature)	8.0	25	Raspberries.	6.0
8	Carrots (young)	4.0	26	Rhubarb	5
9	Cauliflower	7.0	27	Rutabagas	- no data -
10	Celery	10.0	28	Saskatoons	- no data -
11	Chinese Vegetables	- no data -	29	Spinach	3.0
12	Cucumbers	5	30	Squash (summer)	23.9
13	Kohlrabi	- no data -	31	Squash (winter)	- no data -
14	Leafy Greens	- no data -	32	Strawberries	- no data -
15	Leeks	7.0	33	Sweet Corn	7.0
16	Lettuce	3.7	34	Swiss Chard	- no data -
17	Onions	10.0	35	Tomatoes	7.0
18	Parsnips	7.0	36	Zucchini	- no data -

(Adapted from Postharvest Physiology of Perishable Plant Products by Kays, S.J., 1991).

In preparing fresh produce for long term storage, remove free surface moisture on the product. This moisture can support the growth of spoilage bacteria. This situation is particularly true in bruised and cut areas of produce such as root crops. If mechanical damage is minimized and the tops are removed with a clean cut, the removal of free moisture is easier.

The spoilage rate of produce and its contributing factors are the most important considerations when selecting the type of pre-cooling and handling system to be used.

Methods for Pre-Cooling Produce

Pre-cooling rapidly lowers the temperature of freshly harvested produce and is done immediately following harvest to minimize spoilage. There are five principal methods of pre-cooling fresh produce:

- room cooling
- forced-air cooling
- hydro-cooling
- ice cooling
- vacuum cooling

Considerable loss in quality and shelf life can occur as a result of holding harvested produce in the field before pre-cooling. All methods require sufficient refrigeration capacity to reduce the temperature of the produce within the required time plus the ability to remove the normal heat gain in the facility. Table 3 outlines the recommended methods for pre-cooling fruits and vegetables and is followed by a brief description of each of the pre-cooling methods.

Table 3. Recommended Pre-cooling Methods for Fruits and Vegetables

#	Product	Pre-cooling Method	#	Product	Pre-cooling Method
1	Asparagus	hydro-cooling, ice cooling	**19**	Peas	forced-air cooling
2	Beans (green, wax)	forced-air cooling, hydro-cooling	**20**	Peppers	room cooling, forced-air cooling
3	Beets	room cooling	**21**	Potatoes (mature)	room cooling, forced-air cooling
4	Broccoli	ice cooling, hydro-cooling	**22**	Potatoes (new)	room cooling, forced-air cooling
5	Brussel sprouts	forced-air cooling	**23**	Pumpkins	room cooling
6	Cabbage	room cooling, forced-air cooling, hydro-cooling	**24**	Radishes	ice cooling, hydro-cooling
7	Carrots (mature)	hydro-cooling, forced-air cooling	**25**	Raspberries	forced-air cooling
8	Carrots (young)	hydro-cooling, forced-air cooling	**26**	Rhubarb	hydro-cooling, forced-air cooling
9	Cauliflower	forced-air cooling	**27**	Rutabagas	ice cooling, hydro-cooling
10	Celery	forced-air cooling	**28**	Saskatoons (fresh use)	forced-air cooling
11	Chinese Vegetables	forced-air cooling	**29**	Spinach	forced-air cooling
12	Cucumbers	forced-air cooling, hydro-cooling	**30**	Squash (summer)	room cooling, forced-air cooling
13	Kohlrabi	forced-air cooling, ice cooling; hydro-cooling	**31**	Squash (winter)	room cooling, forced-air cooling
14	Leafy Greens	forced-air cooling	**32**	Strawberries	forced-air cooling
15	Leeks	ice cooling	**33**	Sweet Corn	ice cooling, hydro-cooling
16	Lettuce	forced-air cooling, vacuum cooling	**34**	Swiss Chard	forced-air cooling
17	Onions (green)	ice cooling	**35**	Tomatoes	room cooling
18	Parsnips	ice cooling, hydro-cooling	**36**	Zucchini	room cooling

(Information gathered from USDA Handbook #66 and other sources).

- **room cooling**

Room cooling is one method used for produce sensitive to free moisture or surface moisture. Because this type of cooling is slow, room cooling is only appropriate for very small amounts of produce or produce that does not deteriorate rapidly.

Produce is loaded into a refrigerated room or transportation truck. Cold air is circulated within the room and around the produce by the refrigeration fan/s. This is a slow method of pre-cooling because the cold air does not circulate readily through the produce (Figure A). This situation is particulary true for packaged

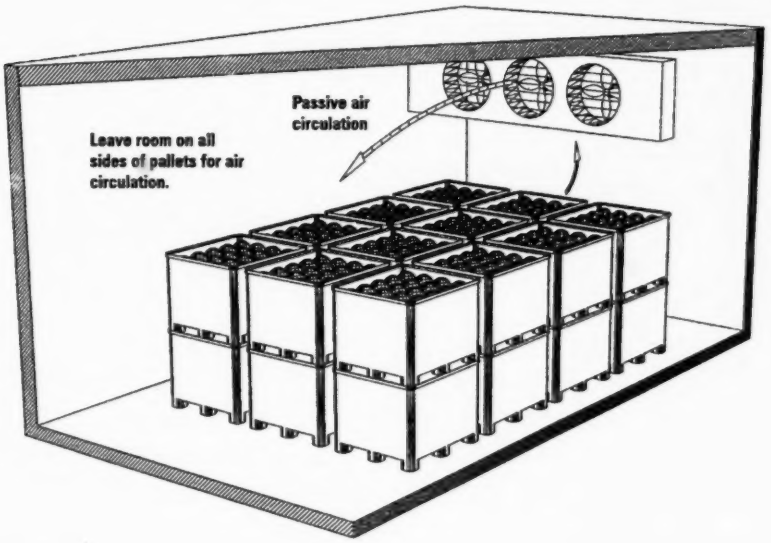

Figure A. **Room cooling is a slow method.**

produce. Room cooling systems are also used for the curing of produce such as winter squash.

- **forced-air cooling**

Forced air cooling is used mainly for bulk produce and palletized produce. It is the most versatile and widely used of all cooling methods. In forced air cooling, chilled air is forced to flow around each piece of produce. This close contact of chilled air with the produce results in rapid, even cooling throughout the mass of produce.

For piled bulk produce, such as carrots and potatoes, air ducts are used to distribute the chilled air through the produce. For palletized produce, pallets loaded with bulk or containerized produce are aligned with air ducts (plenums) that direct chilled air through them.

The air can be channeled to flow either horizontally or vertically. In a horizontal flow system, the air is forced to flow horizontally from one side of the pallet load to the other through holes in the sides of the pallet bin or containers (see Figure B). Only two sides that are opposite can be open in the pallet bin or containers. In stacking containers, the side holes must line up for the air to pass from one side of the stack to the other. In this system, the top and bottom of the pallet or containers must be sealed to prevent air from bypassing the produce.

In a vertical flow system, the air is forced to flow vertically from the bottom to the top of the pallet through holes in the bottom of the pallet, and containers if used, then out the top (see Figure C). In this system, the sides must be sealed to prevent the air from bypassing the produce. Also, if containers are used, the holes in the tops and bottoms of the containers must line up, so the air can travel vertically from one container to the next. This method is faster than room cooling because a flow of chilled air is in direct contact with the produce.

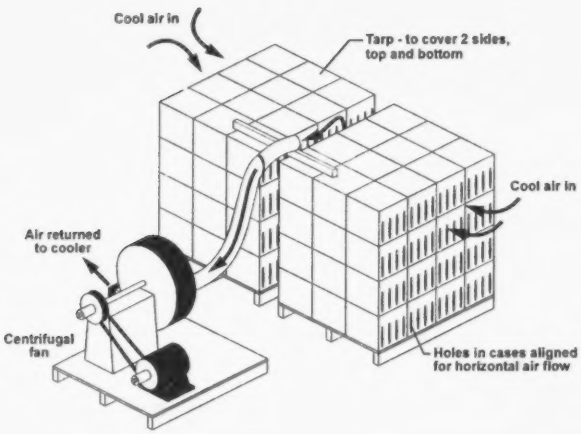
Cool air in
Tarp - to cover 2 sides, top and bottom
Cool air in
Air returned to cooler
Centrifugal fan
Holes in cases aligned for horizontal air flow

Figure B. Forced horizontal air flow.

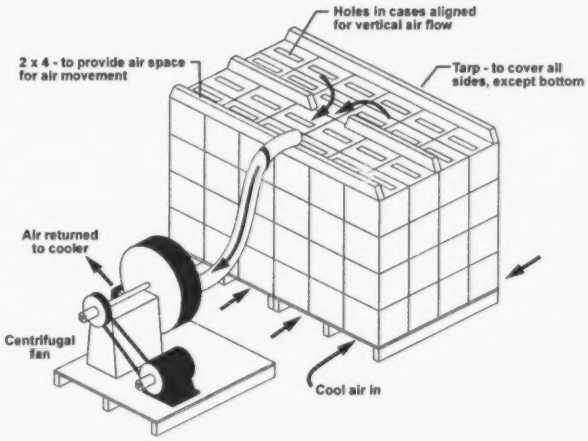
Holes in cases aligned for vertical air flow
2 x 4 - to provide air space for air movement
Tarp - to cover all sides, except bottom
Air returned to cooler
Centrifugal fan
Cool air in

Figure C. Forced vertical air flow.

In these systems, condensation on the produce can be minimized by a simple cover placed on top of the stack of containers, which prevents the entry of ambient air during handling.

To minimize moisture loss in room and forced air cooling, the evaporator of the refrigeration system should have as large a surface area as practical. Also, the evaporator should not be run at a temperature much below freezing as this practice causes undue drying of the air. Excessive air flow should also be avoided to minimize moisture loss.

A bed of chunk or cube ice can be used to provide cooling in place of a refrigeration system. The temperature of the air coming through a bed of melting ice will be in the range of 1 to 4 degrees centigrade and near 100 per cent humidity. See the section on "Ice, A Cold Source for Pre-cooling."

Room and forced air cooling systems are also used for the higher temperature curing of products such as onions, potatoes and squash, before cooling for extended storage.

Some market gardeners own a cold storage facility. Typically, these cold rooms are designed to remove heat from produce and other sources in 24 hours or maybe even longer. With increased refrigeration capacity and a system to force air through the produce, these facilities can also be used to rapidly pre-cool produce.

Mobile versions of forced air systems can be used in the field as an integral part of the harvest operations. Because produce can be loaded into the cooler as soon as it is harvested, cooling can be done within minutes of harvest. By minimizing the holding time before cooling, these systems can be very effective and competitive with other cooling systems that are currently considered as being fast. Mobile systems can also serve as refrigerated shipping systems for local needs.

- **hydro-cooling**

In hydrocooling, cold water is used to pre-cool produce. Produce may be immersed in a tank of circulating cold water or as in other techniques, cold water is sprinkled or sprayed over the produce. The equipment used for hydrocooling is often equipped with a water chiller.

This method of pre-cooling is faster than forced air cooling because water in direct contact with the produce has a higher heat removal capacity than air. If ice is available, it can be used to chill the water. See the section on "Ice, A Cold Source for Pre-cooling."

However, not all types of produce can be hydrocooled. Strawberries and cauliflower, for example, should not be cooled by this method because it results in rapid spoilage of the produce. Hydro-cooling requires particular attention to water quality and sanitation. Chemicals may be used to kill molds and bacteria in the water and on the produce.

- **ice cooling**

In ice cooling, crushed or fine granular ice is used to cool the produce. The ice is either packed around produce in cartons or sacks, or it is made into a slurry with water and injected into waxed cartons packed with produce. The ice then fills the voids around the produce.

Ice cooling is faster than hydrocooling because contact with the produce is good, and ice has a higher heat removal capacity than water. It takes 144 BTUs of energy to melt 1 pound of ice. This amount will theoretically lower the temperature of 4 pounds of produce by at least 36 degrees Fahrenheit.

Ice can also provide cooling for extended periods. It is often a marketing requirement that there be ice remaining in the sacks or cartons of produce at the time it is received by the retailer. As in hydro-cooling, ice cooling requires particular attention to water quality and sanitation. See the section on "Ice, A Cold Source for Pre-cooling."

- **vacuum cooling**

In vacuum cooling, containers of produce are put in a vacuum chamber. Air is drawn out of the chamber creating a high vacuum. Under the high vacuum, the boiling temperature of water is substantially lowered.

For examp! water at the freezing point boils when the pressure is reduced to 0.08859 psi absolute. Normal atmospheric pressure is about 14 psi absolute. As a result, a small amount of water in the warm produce evaporates causing a corresponding lowering of the produce temperature. In some systems, the produce is misted with water to minimize weight loss.

Vacuum cooling is the fastest and most uniform method of pre-cooling because of the high amount of heat required for evaporating the water (about 1000 BTUs per pound of water evaporated). It is, however, one of the most expensive systems to set up.

Because vacuum cooling is a batch process, sufficient produce must be harvested to fill the vacuum cooler before cooling can begin. For the system to be effective, it is imperative that the produce not be held any longer than absolutely necessary after harvest and before cooling. As a result, harvesting and vacuum cooling systems must be very carefully matched.

Other sources of information:
North Carolina State University at www.bae.ncsu.edu/programs/extension/publicat/postharv/index.html

Ice, A Cold Source for Pre-cooling

Ice has characteristics that make it very effective in pre-cooling fruits and vegetables, especially for small-scale market gardeners. These characteristics include its versatility as a cold source for several pre-cooling methods, its thermal storage capacity and its portability.

Ice may be considered stored refrigeration. A small ice-making machine can produce ice continuously for use at a high rate during a short period. The capital cost of the refrigeration system can therefore be a fraction of the cost of a conventional refrigeration system of the same capacity.

Cooling provided by melting ice is naturally regulated at just above freezing with the humidity of air around the ice near 100 per cent. The ice can be used several ways: directly on the produce, or for chilling the water for hydro-cooling, or in an ice bed to chill the air for forced air cooling.

Ice is also very adaptable to pre-cooling in the field as an integral part of the harvest operation. Residual ice in a mobile ice based cooler can also help maintain the temperature of produce during transport. These characteristics make ice ideal for use in cooling most fresh produce.

Many market gardeners do not pre-cool their produce because of the economics involved. By using ice as a cold source, the fixed cost of refrigeration can be substantially reduced, and the benefits of quality produce realized. The adaptability of ice to provide refrigeration for both wet and dry types of pre-cooling can be the basis for low cost pre-cooling of a wide range of fresh produce grown by market gardeners.

If cube or chunk ice is to be used for direct icing of produce, it should be crushed first. Crushed ice can also be used in a slurry with water for injection into cases of produce.

If ice is to provide refrigeration capacity for a forced air system, the air must be able to flow uniformly and easily around each piece of ice in a bin for the air to be chilled efficiently. Cube or chunk ice is best for this purpose. Flake and crushed ice tend to nest in a way that restricts the flow of air.

Pressure drop through an ice bin can be reduced by increasing the area of the bed. The reduced pressure requires less fan energy and, thus, less heat is generated by the fan.

Data and Rules of Thumb for Developing an Ice-based System

- Air required for pre-cooling is about 2 cubic feet per minute per pound of produce. Allow for at least 2 inches water pressure to move the air through the system.
- Air velocity through the floor should be kept below 200 feet per minute to avoid undue pressure drop.
- Specific heat of air is 0.23 BTUs per pound per degree Fahrenheit.
- 1 pound of air is about 14 cubic feet.
- The bulk density of cube ice is about 32.8 pounds per cubic foot.

- Latent heat of ice is 144 BTUs per pound.
- Latent heat of vaporization of water is about 1000 BTUs per pound.
- Specific heat of water is 1 BTU per pound per degree Fahrenheit.
- Maximum depth of ice should not exceed about 18 inches to avoid undue pressure drop.
- Minimum depth of ice at the start of a cooling cycle should not be less than 8 inches to ensure adequate cooling during the time of high temperature difference across the bed.
- Ice bin floors should be 60 per cent open to contain the ice while minimizing pressure loss.
- The shape and size of ice bin floor openings should be such as to contain the shape and size of ice used.
- Cube or chunk ice should be about 1 inch across to minimize pressure loss and provide sufficient surface area for good cooling.
- It takes about 1 pound of ice to cool 2 to 3 pounds of produce. The actual amount depends mainly on temperature of the produce, how well the cooler is insulated and sealed and the ambient temperature.
- Specific heat of high moisture produce is about 0.85 BTUs per pound per degree Fahrenheit

Example Calculations

Here are sample calculations for an ice-based cooling system. The system will be designed for 700 pounds of produce. The produce will be cooled from 70 degrees F to 34 degrees, a decrease in temperature of 36 degrees F.

- 700 pounds of produce requires 700/3 = 233 pounds of ice.
- 233 pounds of ice occupies 233/32.8 = 7.1 cubic feet.
- 700 pounds of produce requires 700 X 2 = 1400 cubic feet per minute of air.
- the minimum area of ice bed is 1400/200 = 7 square feet.
- if the initial depth of the ice is to be 10 inches (10/12 of a foot), the bin floor area will be 7.1/(10/12) = 8.52 square feet.

Other Interesting Calculations and Information

The area of an ice bin floor is determined by the air velocity through it and the amount of ice required. In sizing an ice bed, determine the total amount of ice required for one load of produce. If 280 pounds of ice are required, this amount will fill a volume of 280/32.8 = 8.53 cubic feet. If the depth of ice is initially 1 foot, this amount will require an area of 8.53/1 = 8.53 square feet. This area could be a bin, for example, that is 2.5' X 3.41' = 8.53 square feet.

Tests done by Ike Edeogu in 1998/99 showed that air can be cooled from 70 degrees F to 34 degrees F, a total drop of 36 degrees, with an 8 inch deep bed of cube or chunk ice using an air flow of about 200 cubic feet per minute per square foot of ice bed area, with a pressure drop of 1.41 inches of water.

To calculate the cooling capacity of 1 square foot of ice bin loaded with cube ice to a depth of 8 inches, make the following calculations. If the maximum 200 cubic feet per minute per square foot of air is used, the air will weigh 200/14 = 14.28 pounds. The amount of heat required to heat 14.28 pounds of air by 36 degrees would be 14.28 X 36 X 0.23 = 118.24 BTUs per minute or about 118.24 X 60 = 7094 BTUs per hour per square foot.

To lower the temperature of 1 pound of produce from 70 degrees F to 34 degrees F, or by a total of 36 degrees, would theoretically require 1 X 36 X 0.85 = 30.6 BTUs. This total

would be the equivalent of 30.6/144 = 0.2125 pounds of ice. The ratio of produce to ice would therefore be 1:0.215. Changing this figure to the ratio of ice to produce would theoretically be 1:4.706. A portion of ice, however, is used to offset heat gains from infiltration, fans and lights and through the walls and doors of the facility. The actual ratio of ice to produce used is therefore closer to 1:3. Also, an allowance needs to be made for some ice to cool the unit down.

Index of Manufacturers

Hoshizaki America, Inc.
818 Highway 74 South
Peachtree, Georgia 30269

IMI Cornelius, Inc.
One Cornelius Place
Anoka, MN 55303-1592

Manitowoc Ice Inc.
Sub. of Manitowoc Food Service Group Inc.
P.O. Box 1720, Manitowoc, WI 54221

Mile High Equipment Company
11100 East 45 Avenue
Denver, Colorado 80239

Scotsman Ice Systems
775 Corporate Woods Parkway
Vernon Hills, Illinois 60061

Kold-Draft
1525 East Lake Road
Erie, PA 16511

Storage Systems

Storage systems provide a stable, controlled environment that minimizes deterioration of the fresh produce. These systems can also be adapted to curing and pre-cooling. See Series 6000 plans from Canada Plan Service on the Internet at http://www.cps.gov.on.ca/ for storage systems.

If the storage facilities are to be used for rapid pre-cooling, the capacity of the refrigeration system must be increased. The amount of increase will be determined by the rate of harvest, the desired cooling time and the required temperature drop. The specific heat of fresh produce is about 0.85 BTUs per pound per degree Fahrenheit. For example, if the harvest rate is 1000 pounds per hour, and the cooling is to be done in 0.5 hour and the temperature drop is 40 degrees Fahrenheit, then the system will require an extra 1000 X 40 X 0.85 / 0.5 = 68000 BTUs per hour. Consider ice to be a source of refrigeration. It can dramatically reduce the size of the refrigeration system required by spreading the extra refrigeration load (required for making ice) out over a long period.

Handling Systems

Handling systems must be appropriate, not only for the produce, but also for the pre-cooling, storage, shipping and marketing systems. Handling systems do not add value to the product, but they do have a major effect on the maintenance of produce quality and the cost of post-harvest operations.

The potential for system scale up should also be considered so that the process can be done with minimal changes to the basic system. Equipment and containers used for handling should be easily cleaned and sanitized.

Containers used in handling systems must accommodate the type of cooling to be used as well as the harvesting, handling and shipping operations. In some cases, the containers are used at the retail level as well. Containers require at least 15 per cent open area for the air to enter and 15 per cent open area for the outlet located opposite the inlet. If the containers are to be stacked, the outlets must line up with the inlets to permit air to flow through the stack. Other openings in the containers can result in air bypassing the produce if the flow is not restricted.

Machine-harvested root crops are generally handled in bulk from the field. After washing and grading, these crops may be handled with pallet systems. Corn and some squash may also be handled in bulk from the field.

Green produce and fruit are generally handled with pallet systems from field to market. Some very small operations may use individual containers.

As with all handling systems, the actual handling of produce should be kept to a minimum. If produce can be packed into market-ready containers in the field and immediately pre-cooled, the handling costs can be minimized. In addition, deterioration resulting from holding non-pre-cooled produce, as well as contamination and bruising, can all be kept to a minimum. Market gardeners may find that the additional costs of harvest operations, to accommodate pre-cooling and to reduce contamination and bruising, can be balanced out against the resulting lower handling and produce deterioration costs.

Handling of produce can be done in bulk, in pallet bins and pallets of boxes, trays, baskets, trays of baskets, porous sacks and pails.

- **bulk systems**

Bulk systems can be the cause of considerable damage to the produce if the systems are not carefully designed and operated. Loading and unloading equipment should lower produce as gently as possible to avoid bruising and should avoid exposing the produce to sharp edges. Also, be aware of pressure damage due to produce piled to excessive depths.

Bulk systems are very cost effective if damage to the produce can be minimized. Bulk handling systems can also readily accommodate expansion, again, if damage to the produce is minimized.

- **pallet-based systems**

Pallet-based systems are very versatile and expandable. They can be used in handling, curing, pre-cooling, storage and shipping systems from field to market. Pallet bins can be stacked high without causing pressure damage to the produce. Different lots of

produce can also be kept separate for effective inventory control. Because of these benefits, pallets are the preferred way of handling the wide range of market garden produce.

Pallet bins can be used as an integral part of harvest operations for transport, curing, pre-cooling and storage. In some instances, pallet bins of produce can be shipped directly to market.

Pallet bins used for produce curing and pre-cooling must have perforations. It is best to have slotted holes in only the bottoms of the pallets. This configuration will accommodate vertical forced air, hydro-cooling and ice based pre-cooling systems. Also, natural convection is better accommodated with slot-type perforations in the pallet bottom.

Palletized containers of produce can be handled and managed in a way similar to pallet bins. Totes, trays or cases of produce can be stacked on the pallets in the field. If the produce is to be cooled with forced air, the containers and pallets must have openings that line up when the containers are stacked on the pallets. This alignment is to permit the air to be forced through each of the containers and thus around all the produce.

For vertical flow systems, both the bottom and top of the containers should have at least 15 per cent of the area open. It is much better to have 30 per cent openings if the strength of the containers is not seriously compromised. For horizontal flow systems, opposite sides of the containers should each have 15 per cent openings. Forced air pre-cooling can be done in the field to minimize the time from harvest to cooling, thus optimizing the effects of pre-cooling.

- **individual containers**

Individual container handling systems are generally only appropriate for very small operations. Cases, totes, sacks, pails and baskets can be used in harvest, handling, shipping and marketing operations. They can be handled individually or with the aid of a hand cart.

If these containers are to be used in cooling systems, they must have at least 15 per cent of the bottoms open to allow for air flow and/or drainage. As with palletized systems used with forced air cooling, individual containers must permit the flow of air from one container to the next if forced air cooling is to be effective. Containers used for cooling berries should have slotted holes instead of round ones to minimize air blockage by the berries.

- **open-top totes and containers**

If open-top totes or containers are to be used in a forced-air cooling system, the top of one tote or container needs to seal against the bottom of the one above it.

If this configuration is not feasible, a "mask" (see Figure 9) can be used. A mask is a sheet of material with openings that sits on top of a row of totes or containers. The openings are located over the totes or containers in such a way so that air travels around the produce to chill it. The next row of totes or containers is then stacked, so they are centred over these openings in the mask. This structure forces the chilled air to pass through the containers and not around them.

Developing an Integrated System

Determining the best method for pre-cooling fresh produce is essential for an effective, economic operation. Each type of fruit and vegetable has a preferred method for pre-cooling.

The preferred method for a particular type of produce, however, may not be the most economic for a particular gardener. Most market gardens produce more than one type of produce. It is therefore important, in many cases, to choose systems that are sufficiently versatile for a wide range of produce.

Developing an integrated post-harvest system requires a detailed knowledge of each type of produce, especially the factors associated with produce spoilage and deterioration. Developing an integrated system also means having a thorough knowledge of harvest systems, handling methods, pre-cooling, curing, washing, grading, storage and marketing. With this information, the various types of produce can be grouped together into sub-systems and then individual systems.

The following possible process steps can be used as a guide in deciding on the best configuration for a system. Look at each step and the possible methods for each function for each type of produce. Then, list the methods in order of preference for each type of produce. Include potential new types of produce and upgraded processes.

1. Harvesting
2. Methods for handling at various process stages from field to market
3. Washing
4. Curing
5. Pre-cooling
6. Storage
7. Washing
8. Grading
9. Packaging
10. Handling method
11. Shipping
12. Marketing

Use the Figure D flow chart "general flow options for post-harvest operations" as an aid in identifying the necessary steps for each type of produce. Note: each step has several methods as possible options.

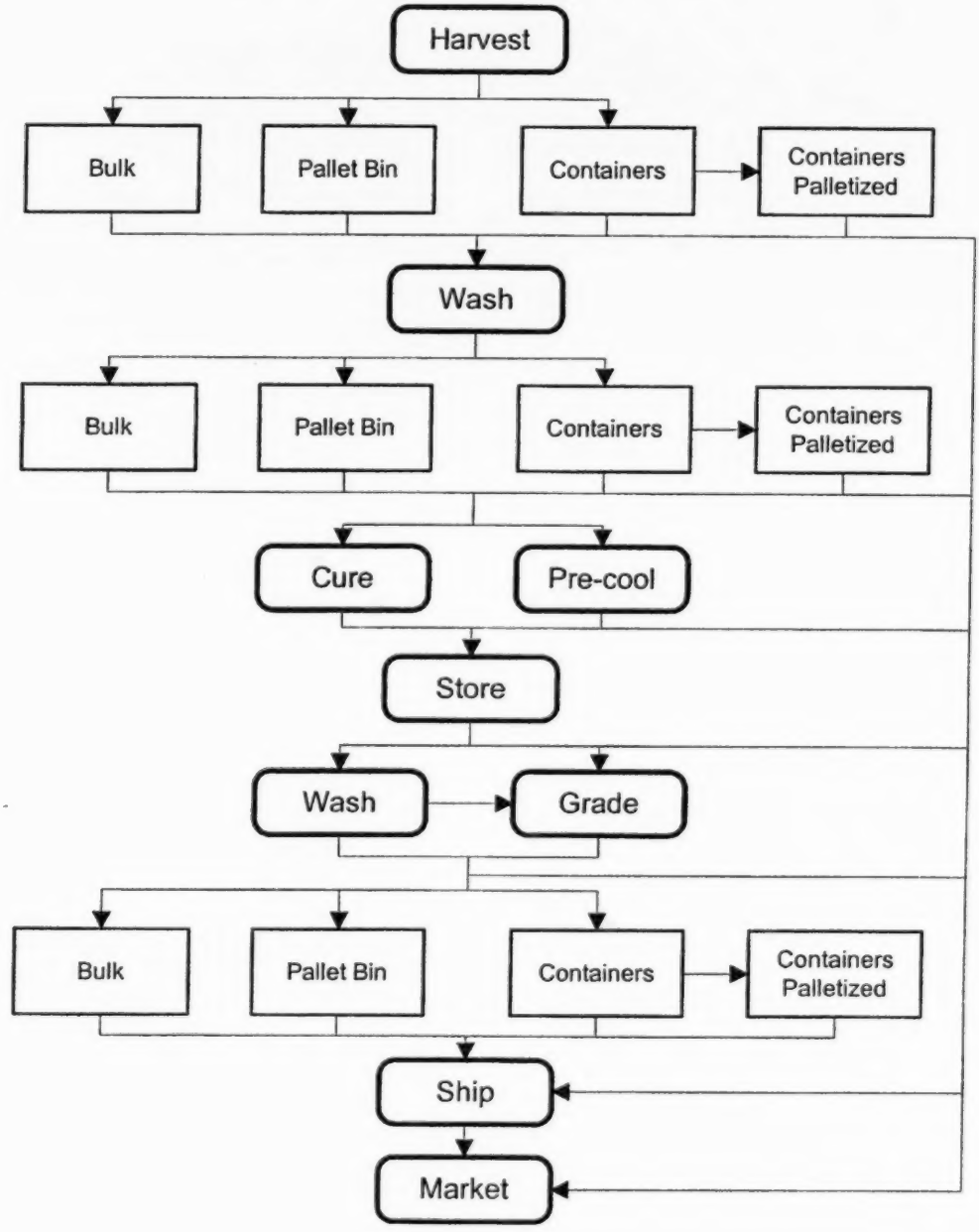

Figure D. **General flow options for post-harvest operations.**

Arrange the types of produce in order of priority for each of the steps. This approach will help define the types of sub-systems to use.

In most cases, a pallet-based handling system will be used. Small operations can start with containers suitable for stacking on pallets, with a later upgrade to the pallet system. Large operations that handle produce in bulk from the field often use pallet systems after washing or grading or for shipping of packaged produce.

Handling systems must have at least the same capacity as the harvest systems. The same handling systems used for harvest are often used for curing, pre-cooling and storage.

Washing systems are generally specific to certain groups of produce. Grading is generally an integral part of the final wash systems, and packaging is generally an integral part of the grading systems.

The pre-cooling systems used, as discussed earlier, depend on the type of product and handling system used. The associated curing and storage requirements are similar to those for pre-cooling. Pre-cooling systems for highly perishable produce require refrigeration capacity that is sufficient to cool the produce at the rate it is harvested. Less perishable produce can be pre-cooled over a longer period, but the pre-cooling should be completed at least within a day of harvest to secure optimum quality.

Consider the use of ice as a source of refrigeration, especially for highly diverse types of operations. Ice can be used in forced air cooling, hydro cooling, top icing, slurry icing and chilling of wash water. It can also provide refrigeration for the short term storage and transport of highly perishable produce.

Curing systems are fairly specific to produce types, and heat is often required. In some cases, curing may even be done in the field.

Storage systems need to take into account the compatibility of produce. This situation includes temperature, humidity, air flow, sensitivity to storage gasses as well as production of odours detrimental to other produce. In most cases, storages used by market gardens need to be divided into rooms with separate controls for temperature and humidity. However, the same handling and shipping systems are often used for produce from separate storages.

Two main objectives in setting up the system:

1. Minimize deterioration of product
2. Minimize handling

Other objectives:

- Have designated and centralized handling areas for moving produce between the various operations.
- Minimize the storage of equipment and materials in the produce storage and processing areas.
- Lay out systems and equipment so that maintenance and cleanup are easily carried out.
- Provide ample drainage inside and outside the facility.
- Provide for expansion of storages and upgrading of processing areas.
- Floors and walls must be easy to clean and sanitize.
- Optimize use of refrigeration capacity.

These pointers should aid in the development of effective, efficient post-harvest systems for market gardeners in Alberta.

Build Your Own Ice-based Cooling System

System Description

The ice-based cooling system described in this section is intended for use in the field as an integral part of harvest operations. It is designed to be mounted on a pick-up truck, but could be modified to mount on a trailer if required.

The unit consists of an enclosure divided into produce, ice bin and engine/fan compartments. A fan forces air down through a bed of ice, along a plenum on the floor, up through containers of produce in the produce compartment and back through the fan. Air exits the ice bed at or below 35 degrees Fahrenheit and near 100 per cent relative humidity, making it ideal for chilling fragile produce. Once the ice starts to melt at 32 degrees Fahrenheit, the air temperature remains relatively constant, making temperature controls unnecessary.

Figures 1 through 17 on the following pages provide detail on each step of the horizontal ice bin system construction.

An alternative to the horizontal ice bin system is a vertical wall ice bin. This system may be appropriate for batch cooling in a central facility. Vertical ice walls require less air pressure due to the distance the air travels through the ice, so the temperature is optimized and consistent.

Because the ice must be loaded in at the top of the wall, an ice machine can be located to load directly into a feed hopper from above, if the unit is in a central facility. Also, regular agitation of the ice in the wall can be done more easily in a central facility. Ice left in the wall can more likely be utilized with greater effectiveness in a central facility as well.

System Specifications

The horizontal ice bin system unit is designed to handle a maximum of about 700 pounds of product. This amount of product will require about 300 pounds of ice to lower the temperature by 50 degrees Fahrenheit.

A generous ice bin area of about 12 square feet is available in the system described. The porous floor should be at least 60 per cent open. The openings should be about $^{3}/_{8}$" across to minimize ice loss. The material should be corrosion resistant or have a corrosion resistant coating.

An air flow of about 1400 cubic feet per minute at 2 inches water pressure is provided for cooling by a centrifugal fan driven by a gasoline engine. The fan has an inlet on one side only. The engine is rated at about 4 horse power. The belt drive should be carefully considered. The belt drive could have a ratio, for example, of about 2.5 to 1 for the fan to run at 1200 RPM with the engine running at 3000 RPM. At this speed, small light engines run fairly smooth under load.

All areas are insulated with 2 inch extruded rigid polystyrene foam. Separate exterior doors provide access to the produce area, engine compartment and ice bin. The tail gate of the truck is left on to provide a standing area for

loading and unloading the produce. Drains for water from the melting ice are provided in the ice bin area, which requires appropriately located drain holes in the truck box.

Containers used in the system must accommodate the vertical flow of air through them. This approach means that the holes are only in the bottom of the containers and in the top when applicable. A mask on the floor plenum directs chilled air up through the bottoms of the containers. A mask is a sheet of material, such as plywood, that has cut-outs that the containers are stacked on to direct the flow of air through only the bottoms of the containers.

A relatively air tight seal is also required between stacked containers to ensure a positive flow of air through the produce in all the containers. This flow may be achieved with just the containers if a relatively tight seal can be made between the top and bottom of the stacked containers. A second method makes use of a mask similar to the one on the floor. This mask is then installed between each layer of containers.

Fabrication

Fabrication of the cooler requires good basic shop skills. Plans for the cooler have been kept general because of the wide range of truck box configurations, fans, engines, fabrication methods and construction materials that could be used. Basic concepts of the system should be adhered to so the unit will function efficiently. The unit requires the following:

- A recirculating and positive vertical flow of cooling air from the fan, through the ice bin, through the produce and back through the fan.
- Fan located so air is supplied to it from the produce area and not the ice bin area. Heat is added to the air by the fan in the process of compressing and moving the air. It is also more difficult to achieve a uniform flow of air through the produce if the high velocity air from the fan discharge is close to the produce air inlet.
- Insulate and seal refrigerated compartments and fan to minimize heat gain and optimize cooling effect of ice.
- A generous ice floor area to minimize air pressure required.
- Containers that are easy to handle, provide for vertical air flow only and can be easily cleaned and stacked.

Construction of the cooler is described in Figures 1 through 17. Materials open to the ice bin and produce compartments should be selected to avoid contamination of the produce. Pressure-treated wood or exposed fiberglass insulation are to be avoided. Consider cedar for ice bin and produce frames. Clean and coat all metal components to minimize rust.

Modifications may be required to the top portion of the unit if the unit is to be removed and installed often. For example, corner jacks or lifting brackets may be installed.

Operation

1. Load empty containers into produce compartment.
2. Determine the amount of ice required and load into ice bin. Use cube or cylindrical ice. Flake ice and fine granular types of ice restrict the flow of air. Use about 1 pound of ice cubes for every 2 to 3 pounds of produce – more on hot days less on cold days.

3. Move cooler to a location in the field that is central to harvest operations.
4. Unload containers.
5. Ensure ice bin and produce doors are closed; start fan to cool down the unit.
6. Harvest produce and fill containers.
7. Load containers of produce into cooler as they are filled, so they can be cooling as soon as possible.
8. Monitor ice bin and adjust ice levels if required. Some areas may melt faster than others. Stack the ice deeper in these areas.
9. Continue loading until unit is full or harvest is done.
10. Continue cooling until the top containers are chilled. At this point, the ice should be nearly used up. Air pressure drop through the system at the start will be due to the depth of ice, while near the end of loading, the pressure drop will be due mainly to the depth of product.
11. Use the cooler unit to transport and store the cooled produce. If the produce is to be held in the cooler for a substantial time, more ice will be required, and the fan will need to be run periodically to maintain the temperature. Be aware that some circulation of air will result from convective forces.
12. For high harvest rates where a central pre-cooler is available, only a portion of the cooling may be done in the mobile cooler. The mobile cooler can be unloaded into the central facility, allowing the mobile unit to return to the field to support harvest operations.

Maintenance

After use, clean and dry out the mobile cooler. Store the unit inside if possible, so the doors can be left open to dry and air out. When the unit is to be stored for long periods, make sure that the gasoline is drained completely from the tank and that the engine has clean oil in it.

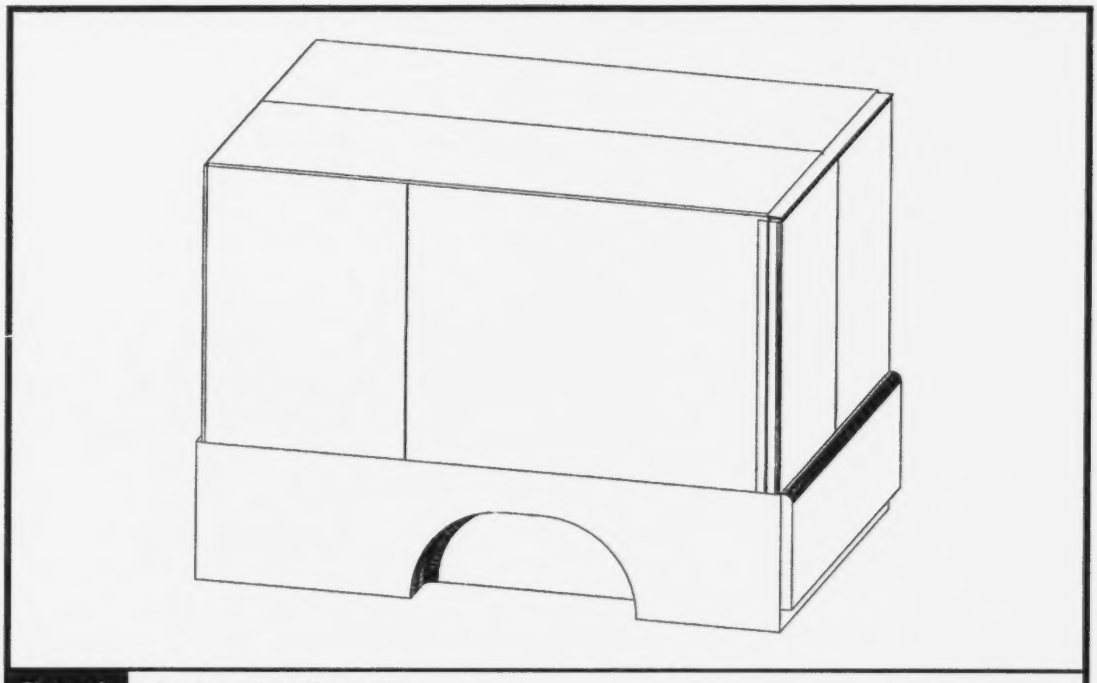

Figure 1. Ice-based cooling system.

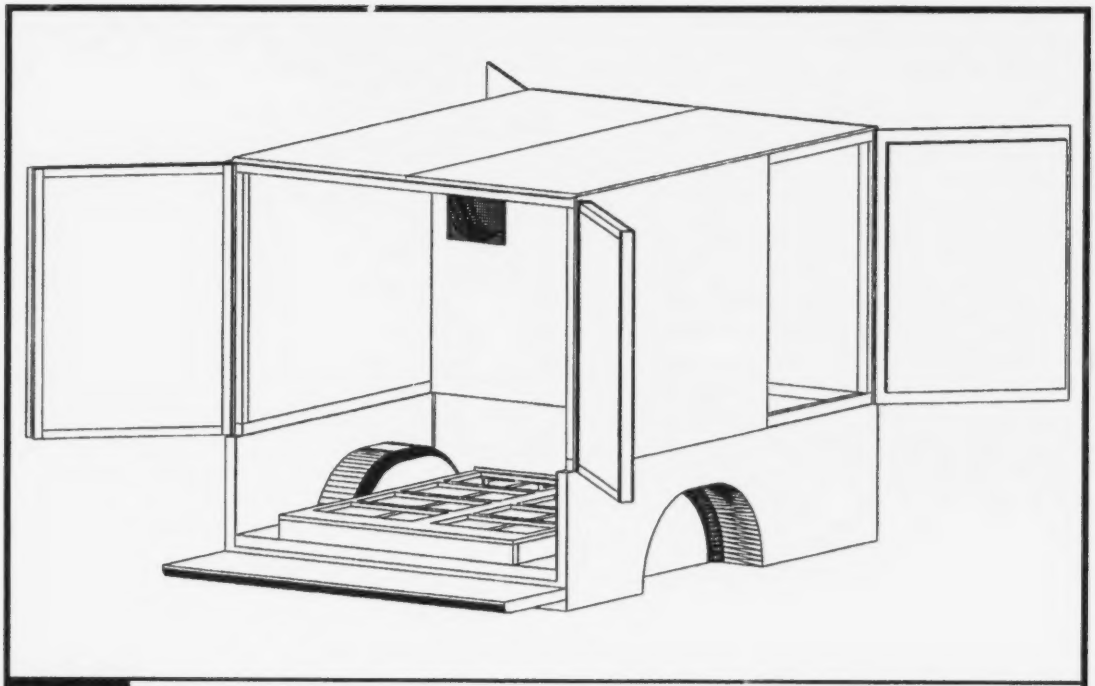

Figure 2. Produce/ice bin access view.

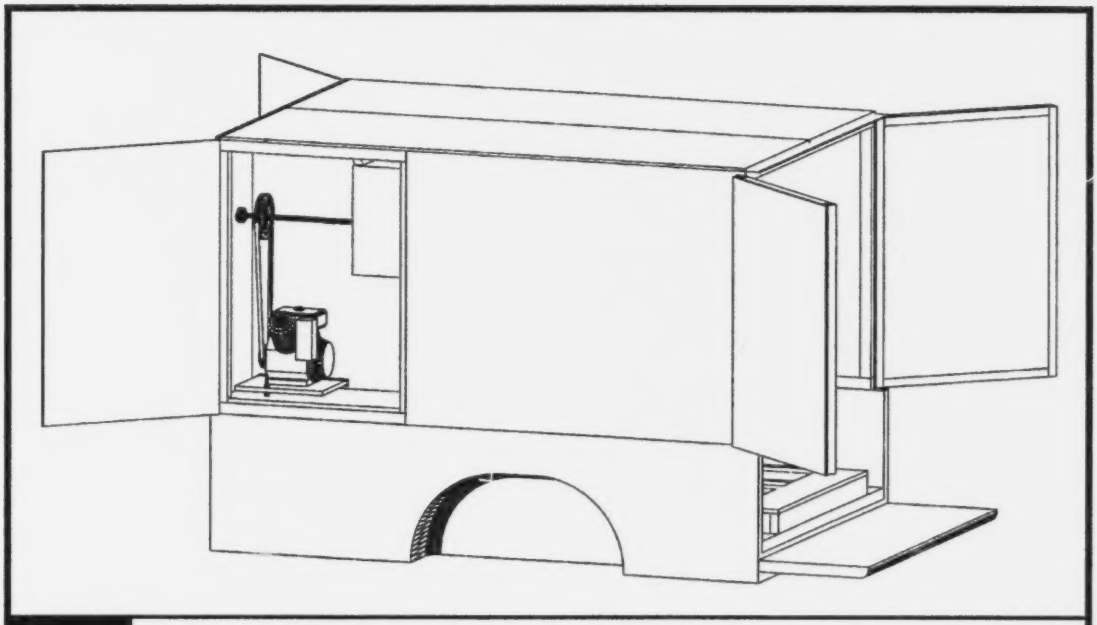

Figure 3. **Engine/fan side view.**

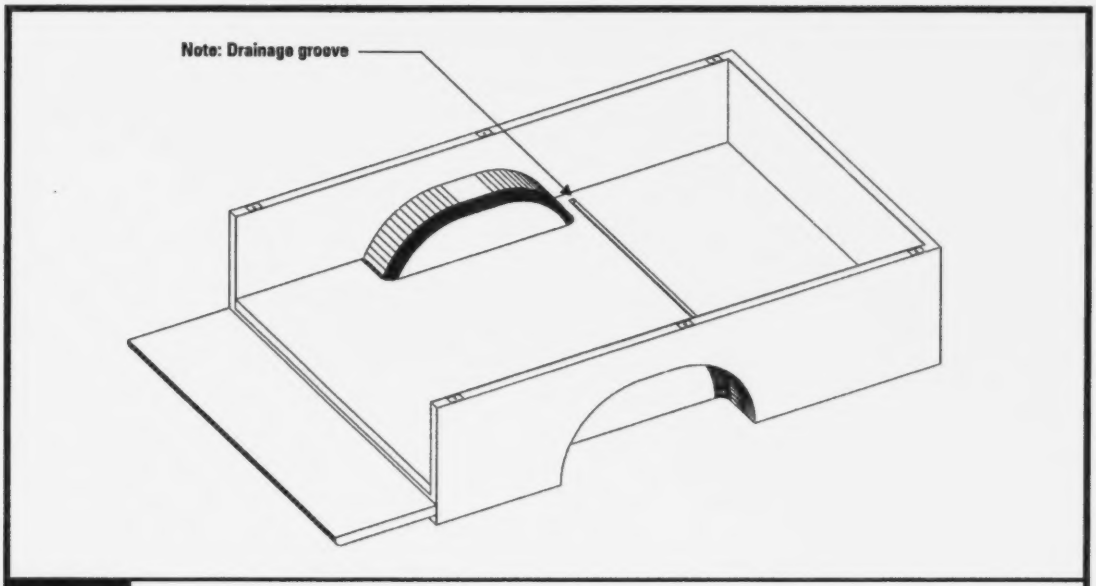

Figure 4. **Truck box insulation and drains.**

Notes: Insulate floor with 2" rigid extruded foam. Cut 1" x 1" groove in foam as shown to drain water from melted ice. Locate the groove about 5" in front of the wheel wells. Also provide drainage from these holes from the truck box. Also insulate walls and wheel wells of truck box. Protection of the back edge of the floor insulation may be done with a length of 2" x 1½" wood.

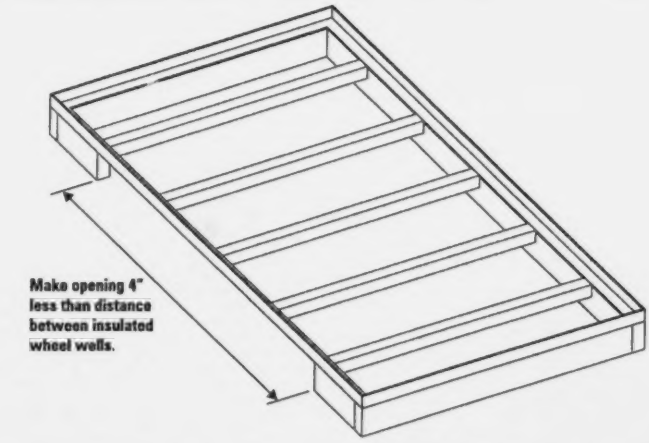

Figure 5. **Ice bin frame.**

Notes: The ice bin fills the space in front of the wheel wells. It is made of 2 x 4s and angle iron. The angle iron is 1½" x 1½" x ⅛". Fabricate as shown to fit in front of the wheel wells with insulation installed in truck box. Allow at least ¾" on the front and sides of the frame for clearance and the ½" thick walls of the ice bin. Allow ½" on the back of the frame for the ½" thick rear wall of the ice bin. The angle iron floor frame can simply rest on top of the 2 x 4s because the ice bin walls will keep it in place when they are installed.

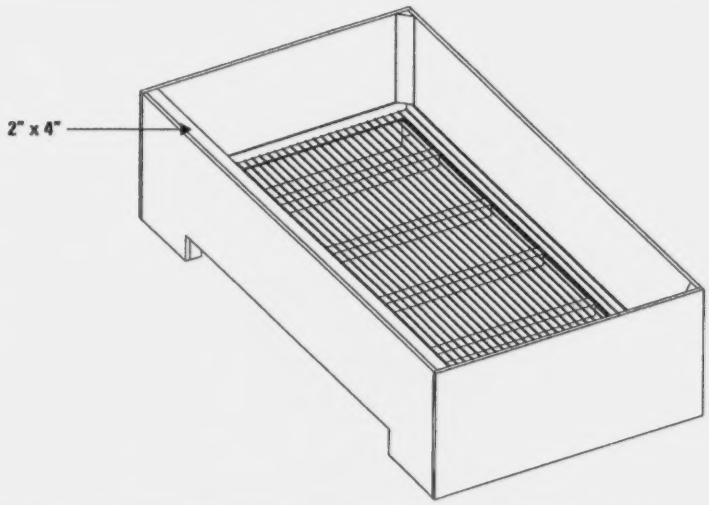

Figure 6. **Assembled ice bin.**

Notes: The grate or mesh to be used for the floor of the ice bin should have openings about ⅜" across to minimize loss of ice and yet let the air pass freely. The mesh should be cut to fit inside the angle iron frame. ½" plywood can be used for the ice bin walls. The top of the bin should be made so that it will be level with the top of the truck box when the bin is installed. The rear wall of the ice bin must have a cut out at the bottom that is 3½" high by 4" less than the distance between the insulated wheel wells. The top of the bin requires reinforcing with a 2 x 4 installed as shown. The bin is now ready for installation in the front of the truck box.

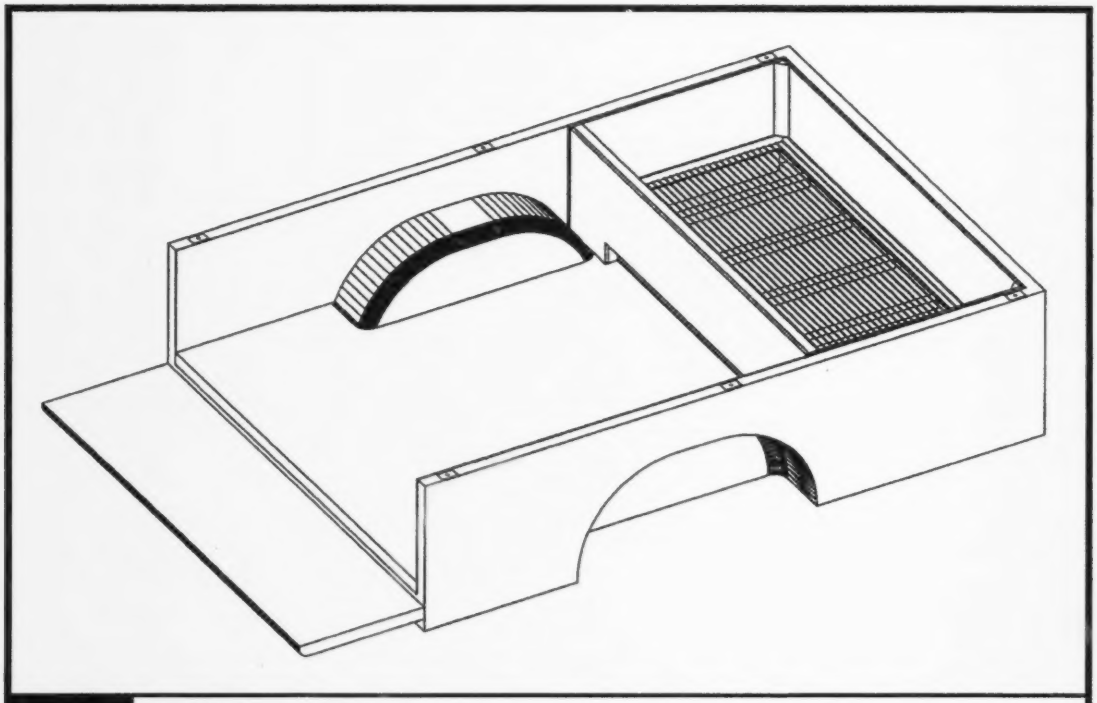

Figure 7. **Installation of ice bin.**

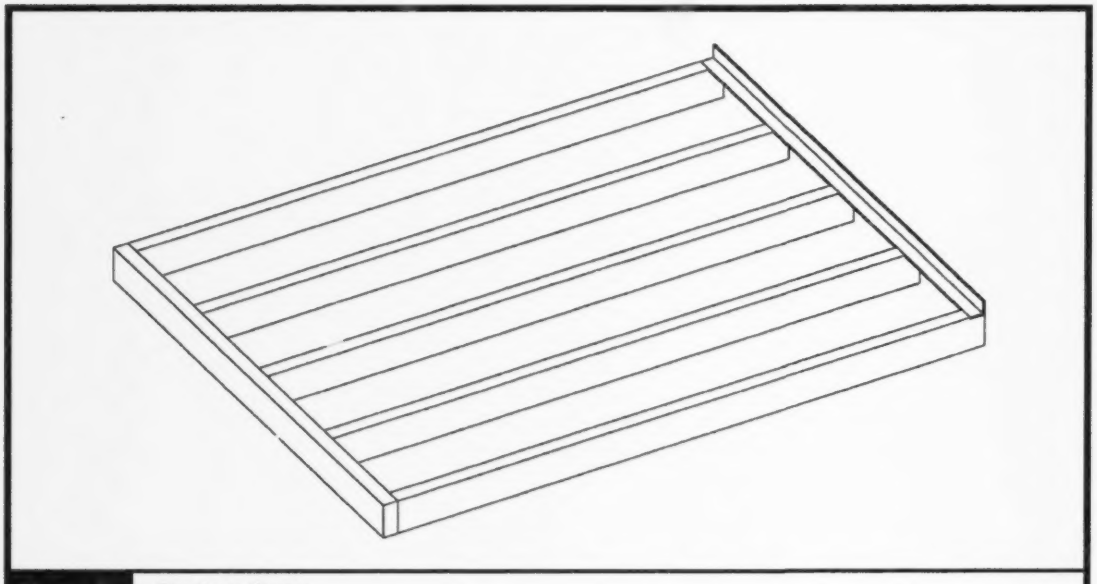

Figure 8. **Produce frame.**

Notes: The produce frame holds the produce off the floor so that the refrigerated air can be forced up through the produce. The frame is made from 2 x 4s with a length of angle iron (1½" x 1½" x ⅛") at the front. Notch the angle iron flush into the 2 x 4s. It is suggested that the frame members be held together with 3" deck screws. Do not make the frame too long as it will prevent closure of the tail gate.

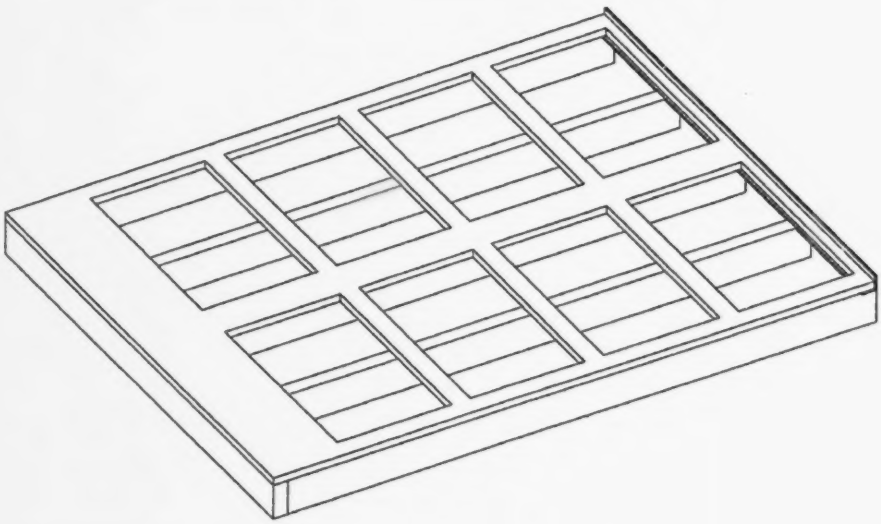

Figure 9. **Produce mask installation.**

Notes: The produce mask forces the cooling air to pass through the bottoms of the produce containers and not around the outsides of them. The mask can be made from ½" plywood. The shape, size and arrangements of the openings will be determined by the containers that will be used and their arrangement.

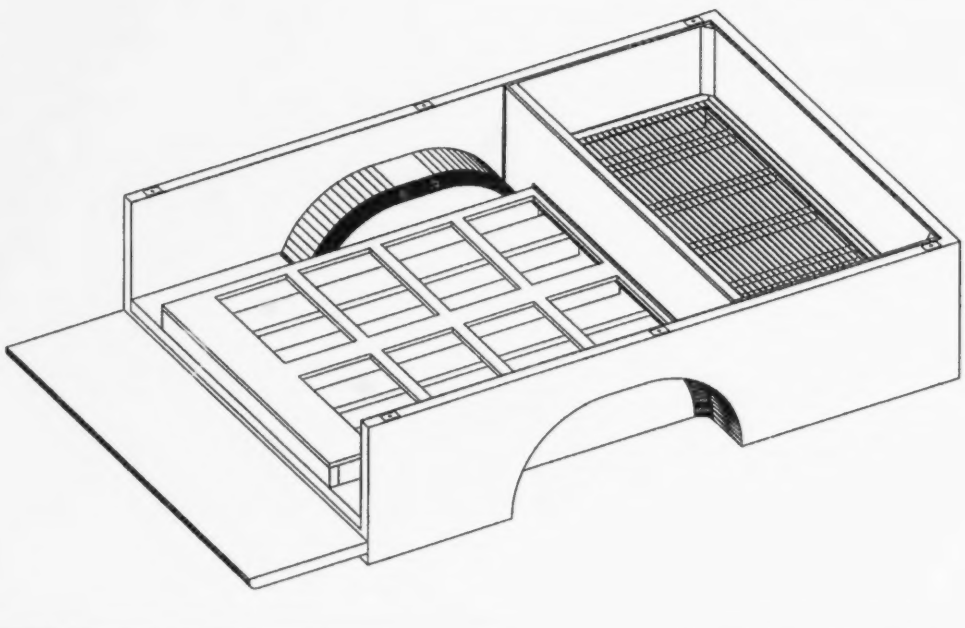

Figure 10. **Installation of produce floor.**

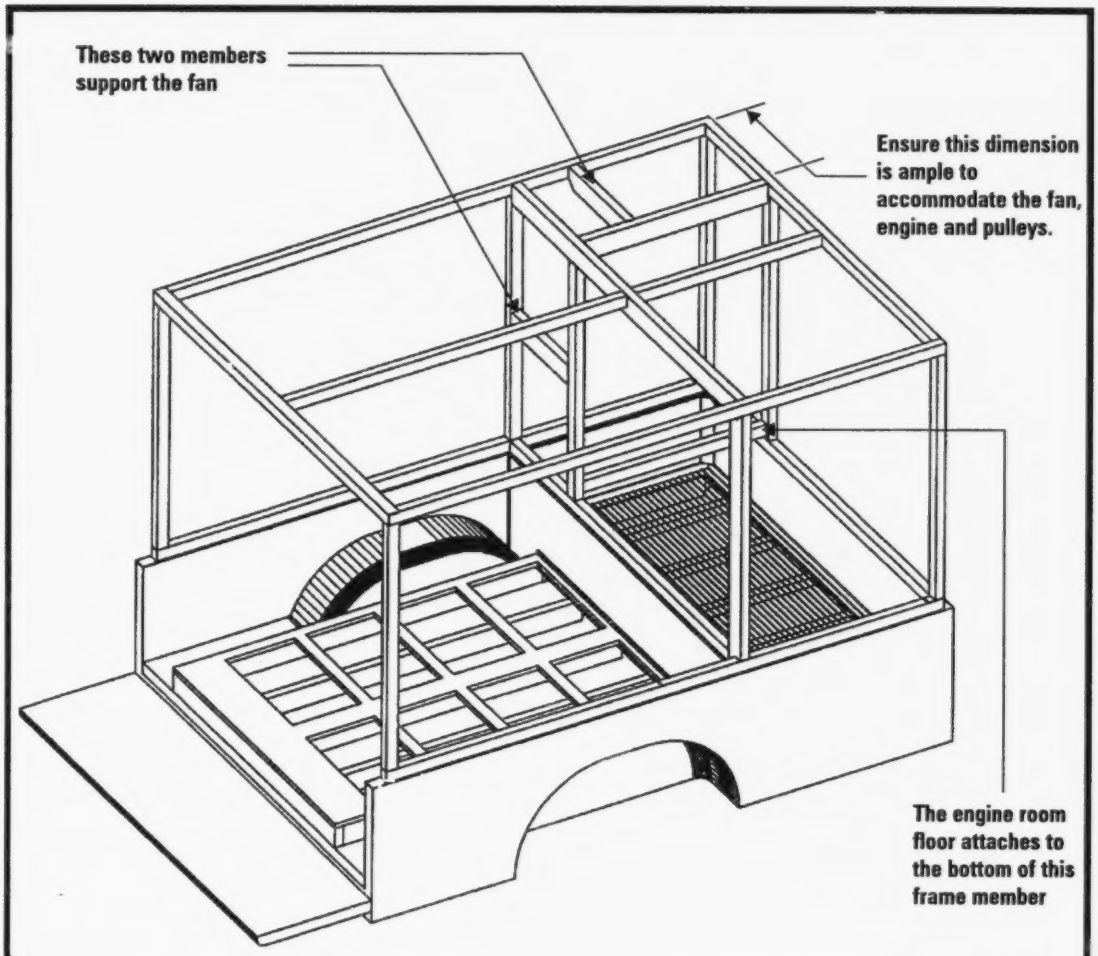
These two members support the fan
Ensure this dimension is ample to accommodate the fan, engine and pulleys.
The engine room floor attaches to the bottom of this frame member

Figure 11. **Cooler frame.**

Notes: The cooler frame is made of 1½" x 2" and 2 x 4 spruce with a 1½" x 1½" x $\frac{1}{8}$" angle iron header above the rear doors. 3" deck screws are recommended for fastening the frame together. The frame must be no longer than 8 feet to accommodate the plywood cladding. The overall height of the frame should be 4 feet to accommodate the 4 foot width of plywood cladding required. Take care to ensure the frame seals against the top of the ice bin wall. Also ensure that the back of the frame will be located so that the doors can be installed to provide a seal at the tail gate. The angle iron header at the upper back of the frame requires recessing so that it is flush with the wood members. Install a foam seal between the frame and truck box. Attach the frame at the truck stake pockets. Note that some truck boxes are tapered from front to back.

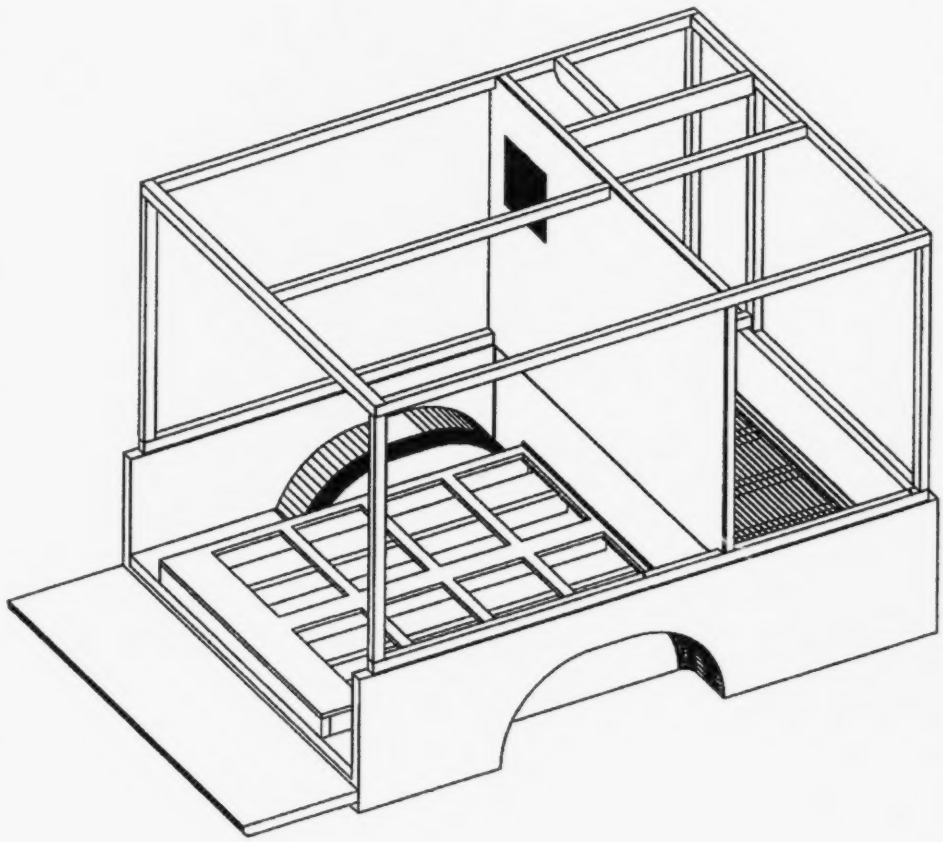

Figure 12. **Bulkhead wall.**

Notes: The bulkhead wall can be made from 3/8" plywood. It will require notching to fit around the framing members. The hole for the inlet of the fan should be accurately cut so that it provides a seal without restricting air flow. Install a welded mesh screen with ½" openings over the fan inlet hole.

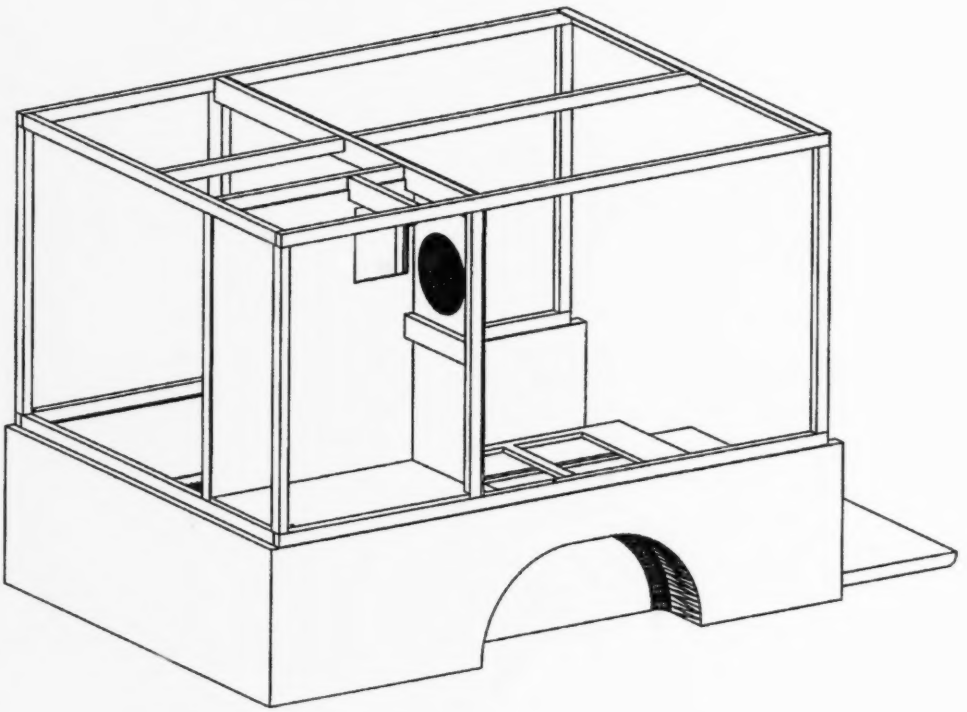

Figure 13. **Engine compartment.**

Notes: The engine room cladding must be installed so that fumes and spilled oil and gasoline will not get into the rest of the unit. Cut and install the floor first. Note that the back edge is attached to the underside of the frame member. Cut and position the back panel. Accurately locate and cut the hole for the fan. Install the panel and seal all joints.

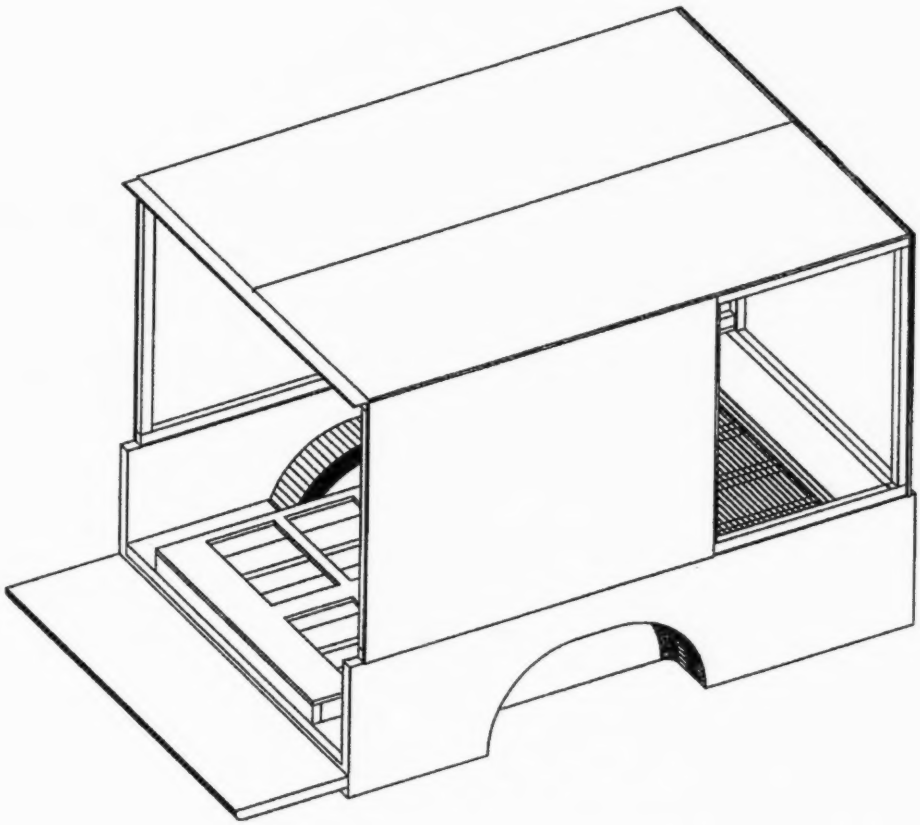

Figure 14. Installation of cladding.

Notes: Cladding should be 3/8" or preferably ½" plywood. Install sides first. At the door openings for the engine and ice bin, ensure that the cladding covers only ½" of the width of the door frame member. This step is to provide stops for the doors to seal against. Use deck screws to fasten the cladding. Install the front cladding. Fabricate and install the front and rear drip caps. Install roof cladding using a flexible caulking to seal the joints. Also complete sealing of the engine compartment.

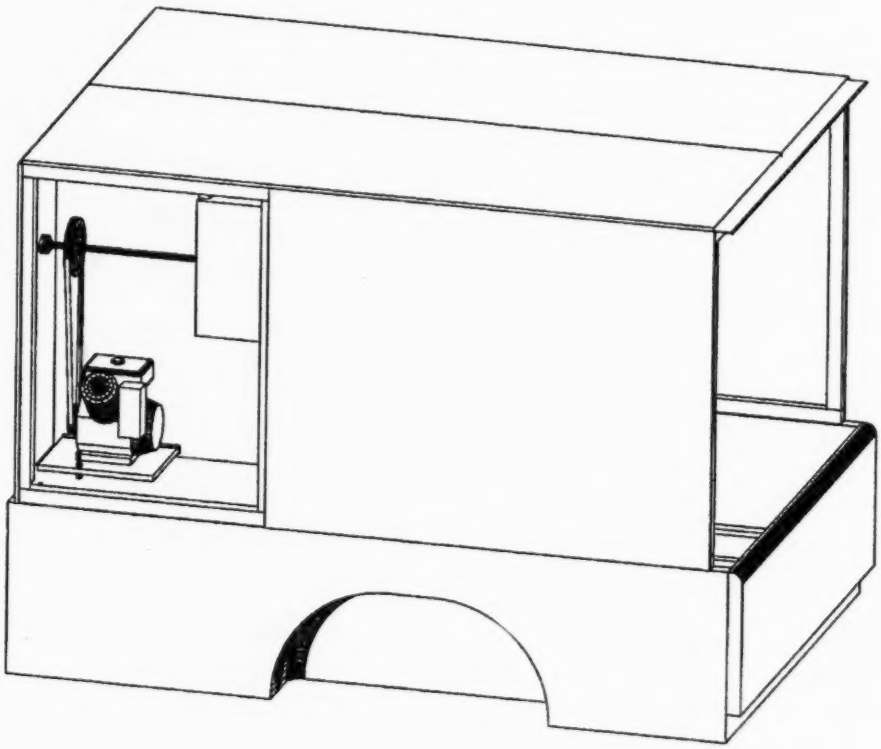

Figure 15. **Fan and engine installation.**

Notes: Prepare the engine compartment by sealing and painting with an oil-based paint. A galvanized metal pan may be installed on the floor of the compartment to contain spills of fuel and oil.

Fan installation – Insulate the fan housing with self-adhesive foil-back foam insulation. The shaft of the fan will need to be replaced with a longer one. Make the shaft long enough to replace the existing shaft plus reach to within a half inch of the front cladding of the engine compartment. Slide a large felt washer and back-up collar on the shaft to provide a seal between the fan housing and shaft. Slide the fan pulley and flange bearing on the shaft. Install the fan assembly, securing it on the frame members provided. Seal around the fan inlet and outlet. Slide the belt on the shaft. Align shaft and install flange bearing on front wall of engine compartment.

Engine installation – Fabricate hinged engine mount and drill for engine mount bolts. Install hinged engine mount. Install engine and belt tensioning bolt. Align and secure pulleys and install and tighten belt.

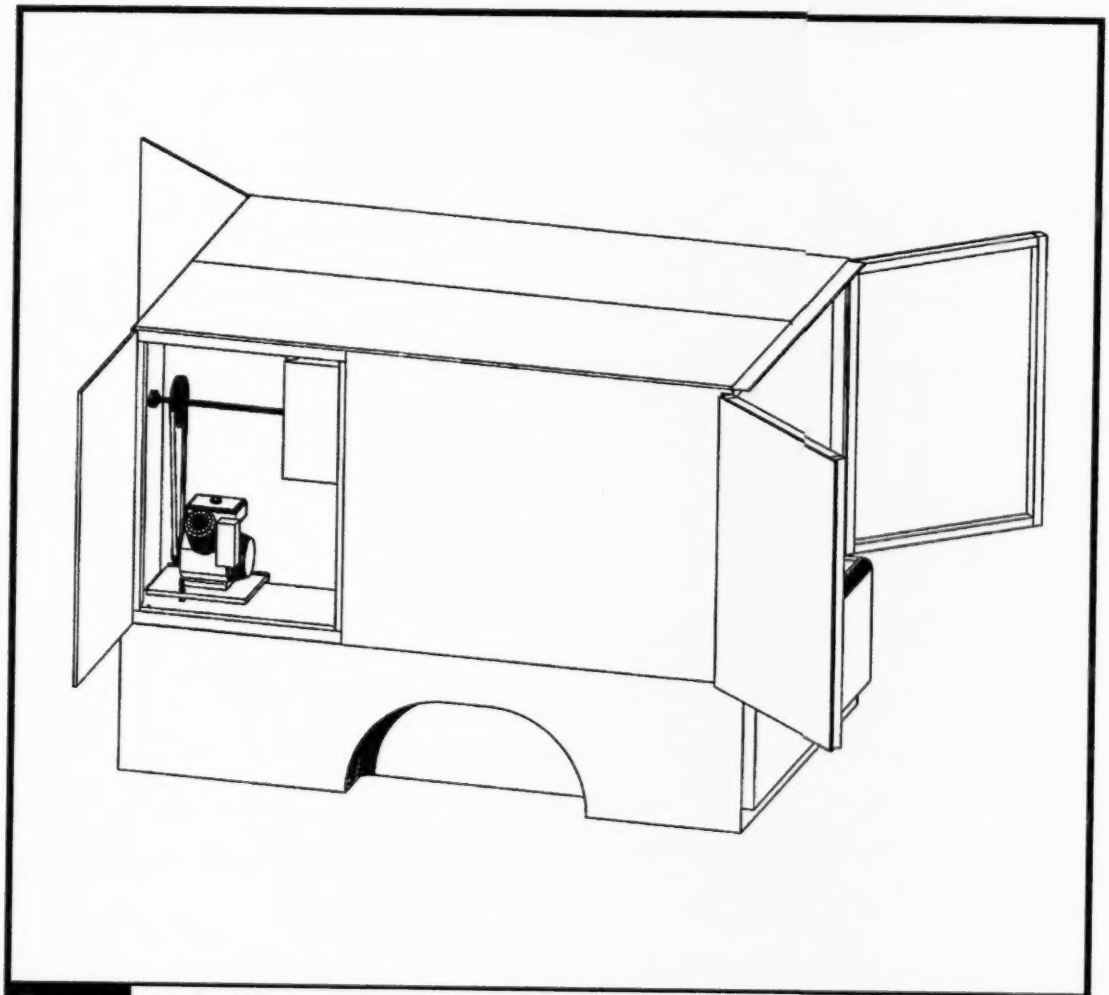

Figure 16. **Door installation.**

Notes: Engine room and ice bin doors – fabricate from ½" plywood and install with continuous type hinges. The ice bin door requires a seal and at least two latch points to contain the air pressure in the ice bin area. Use a type of latch that will not work its way open during travel.
Rear produce doors – fabricate door frames from 1½" x 2" spruce. Orient the 2" dimension to accommodate the 2" insulation. Install ½" plywood cladding. Note overlap where doors meet in the centre. Install hinges and hang doors. A system will be required to latch the last door closed to the header. The system will also be required to iatch the two doors together at a point about one foot from the bottom of the doors. See truck body suppliers and manufacturers for hardware.

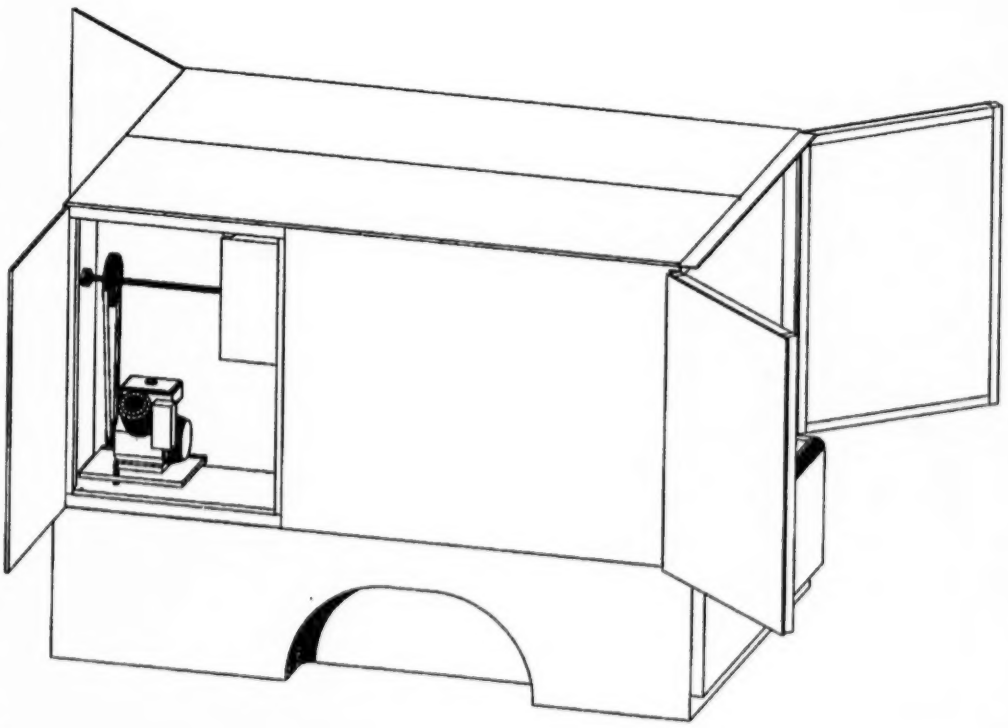

Figure 17. **Installation of insulation.**

Notes: Use 2" extruded rigid foam and hold it in place with adhesive designed for the purpose. Insulate all wall and door areas except the bulkhead in both the ice bin and produce areas. The engine room area of the bulkhead around the fan should also be insulated. This insulation may need to be done on the engine room side of the bulkhead.